ECE 413/513 –RADIO FREQUENCY IC DESIGN

COURSE INTRODUCTION

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COURSE OUTLINE

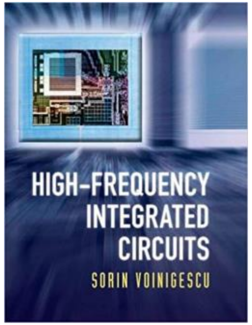
Course Site : http://lumerink.com/courses/ece513/f18/ECE513.htm

COURSE TOPICS

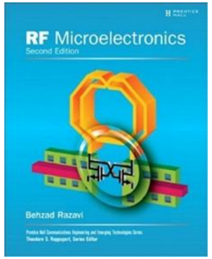
- Radio Frequency (RF) Transceivers: Basics and Architectures
- Fundamentals:
  - Two-port networks
  - Distortion and Noise
  - Matching, Smith Chart use
  - RF Link budget analysis
- High-frequency MOSFETs
- Tuned amplifier design and analysis
- Low-noise amplifiers (LNA)
- Mixers
- Oscillators (PLLs covered in ECE 504)
- Power Amplifiers (if time permits)

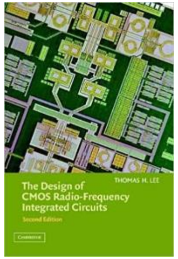
REFERENCES

- **Textbook:**
  - High-Frequency Integrated Circuits, S. Voinigescu, 1st edition, Cambridge, 2013.



- **Additional References:**
  - RF Microelectronics , B. Razavi, 2nd Edition, Prentice Hall, 2011
  - The Design of CMOS Radio-Frequency Integrated Circuits, T. H. Lee, 2nd edition, Cambridge, 2003.





COURSE PEDAGOGY AND GRADING

- Combination of lecture notes and slides
  - Lecture notes to be posted online
  - Additional slides, Matlab code etc. will also be posted on the site
- Workload (Grading)
  - Homeworks (25%)
  - Midterm Exam (25%)
  - Project 1 (25%)
  - Final Exam or Project 2 (25%)
- Cadence is used for design-based HWs and Projects

COURSE POLICIES

- No late work
- Neither the final exam nor final project will be returned at the end of the semester
- No internet surfing in class on any device
- Plagiarism and outsourcing (!) of work is not acceptable (See UoI Policy).
- See detailed policies on the course site

ANALOG IC COURSES AT UI

ECE 410

- Microelectronics II

ECE 515

–Analog IC Design

ECE 517

– Mixed-Signal IC Design

ECE 513

– RF IC Design

ECE 519

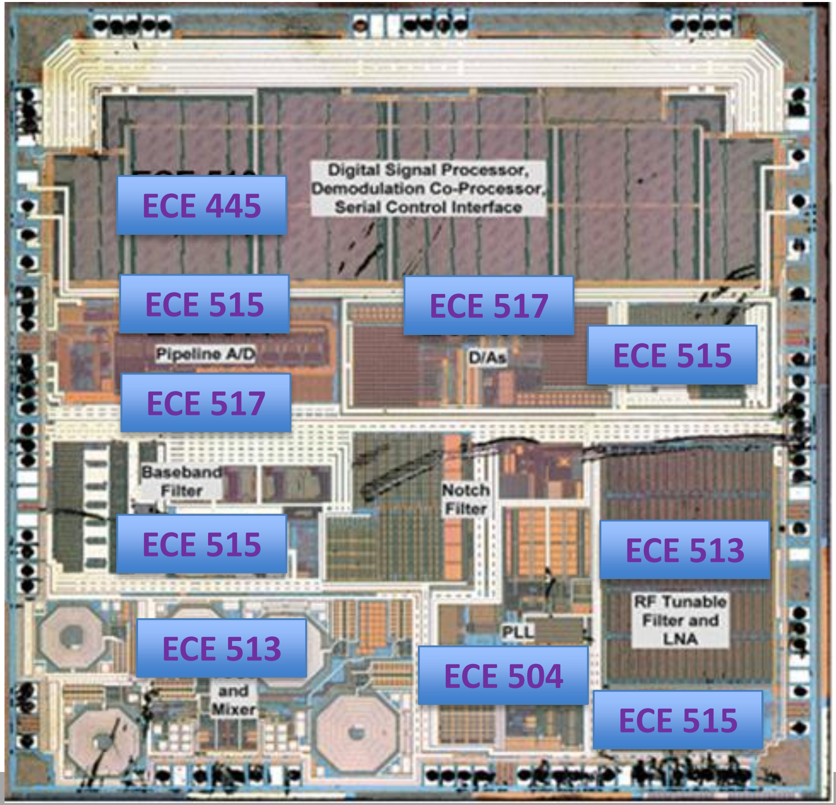
– CMOS Imager Design

ECE 504

–PLL and High-speed Link Design

ECE 504-X

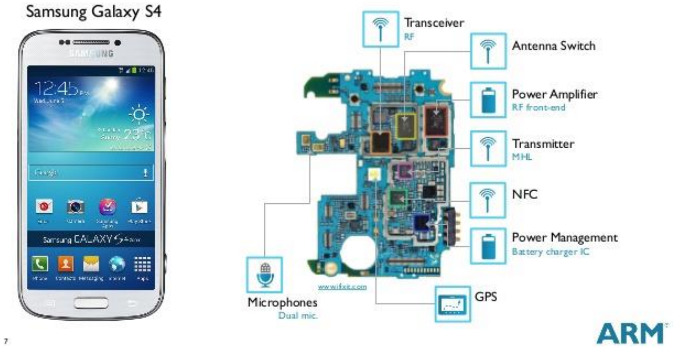
– Other Advanced Topics in IC Design



REVIEW

- Brush up on Analog Circuit Design basics (ECE 410)
  - http://lumerink.com/courses/ece5411/s11/Lectures.htm
- Signals and Systems
  - Frequency domain understanding, modulation and demodulation from your undergrad textbook
- Review Smith Chart
  - https://www.youtube.com/watch?v=hmqM8PnUkmo&t=380s

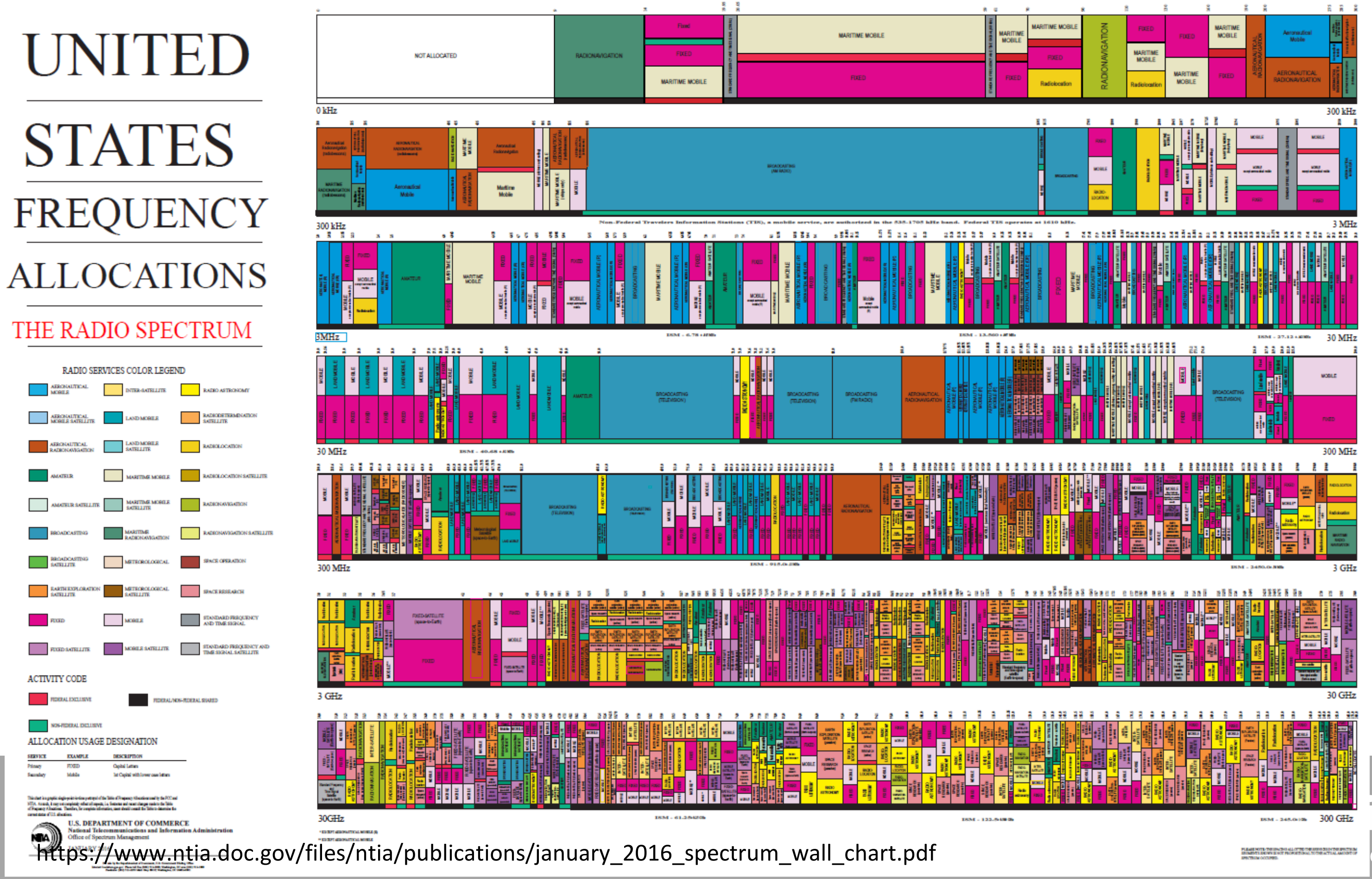
WIRELESS TRANSCEIVERS



https://pt.slideshare.net/SatyaHarish1/wearables-show-march-2015

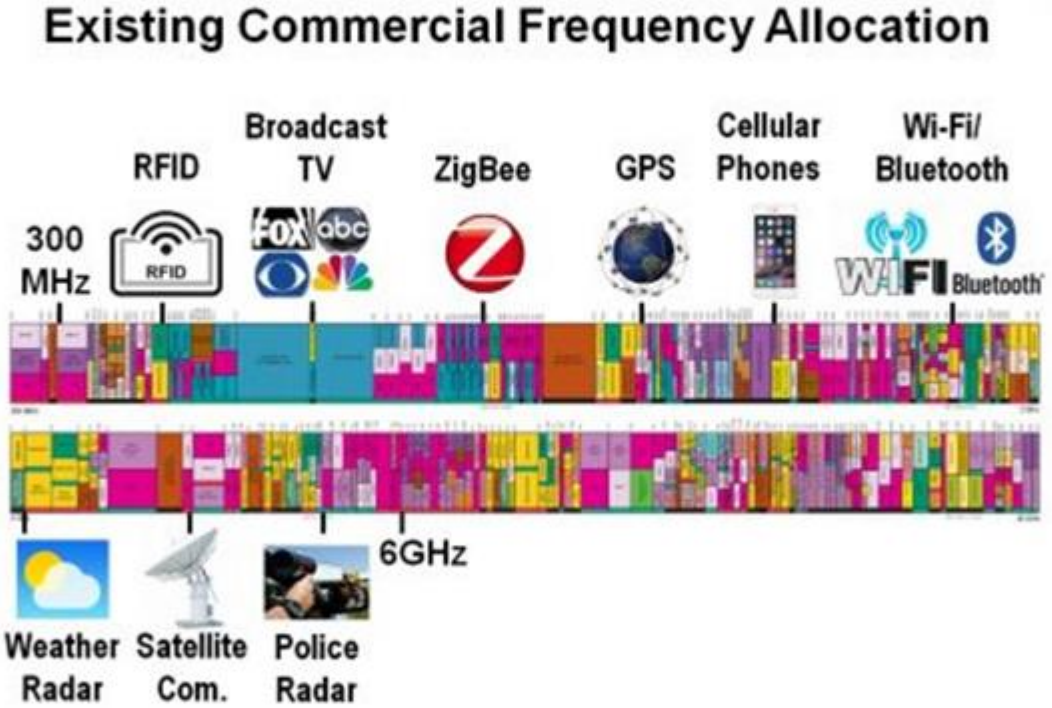
- ‘Radio’ transceivers are ubiquitous and indispensable
- Cellular, internet of things, satellite, military, RADAR,………
- Recent activity in 5G wireless extended to 28GHz, 60GHz and higher frequency bands

SPECTRUM ALLOCATION



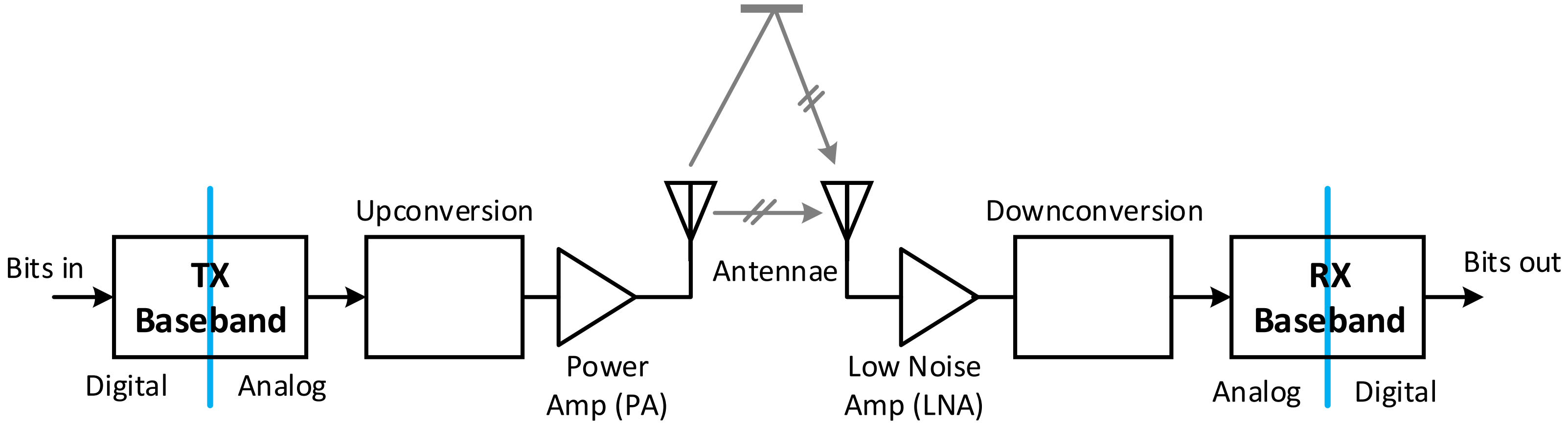
https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

RF SPECTRUM ALLOCATION



https://www.ee.washington.edu/spotlight/uw-radio-researchers-break-world-record-with-full-duplex-communication/

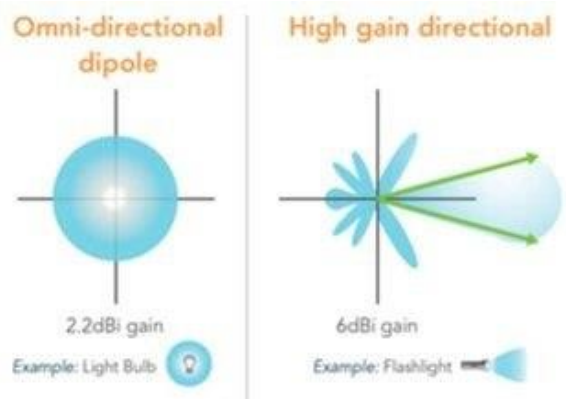
RF TRANSCEIVERS



ANTENNA BASICS

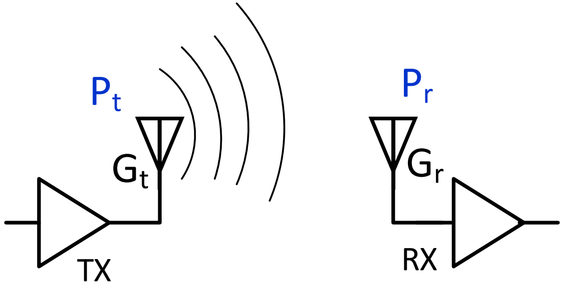
ANTENNAS

- Antennas ‘match’ the energy on a transmission line to a propagating wave in free space (377Ω impedance)
  - Essentially a passive device with an input impedance, efficiency, gain and directivity
- Higher gain implies higher directivity.
  - Omnidirectional antenna has lower gain (think of light bulb) than an antenna with high directivity (think of flashlight)
- Efficient antennas have dimensions roughly equal to the free space propagation wavelength (λ)



Ali Niknejad, “Advanced Communication Integrated Circuits” UC Berkeley, 2015.

FRIIS PROPAGATION EQUATION



Received power $P_r = G_t \cdot \frac{P_t}{4\pi r^2} \cdot A_{er}$

TX power over surface area of sphere

$$A_{er} = \frac{\lambda^2}{4\pi} G_r$$

Effective aperture of the RX

$$\frac{P_r}{P_t} = \frac{A_{e1} A_{e2}}{r^2 \lambda^2} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2}$$

G_t: Gain of TX antenna
G_r: Gain of RX antenna
r: Line of sight distance

Ali Niknejad, “Advanced Communication Integrated Circuits” UC Berkeley, 2015.

FRIIS PROPAGATION EQUATION

$$\frac{P_r}{P_t} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2} = \frac{G_t G_r}{\left(\frac{4\pi r f_c}{c}\right)^2}$$

$$P_r|_{dB} = P_t|_{dB} + G_t|_{dB} + G_r|_{dB} + 20 \cdot log_{10} \frac{\lambda}{4\pi r}$$

- For a fixed antenna gain (directivity), the attenuation increases as f^2
  - Capture area at RX antenna is proportional to λ^2, which is decreasing with f

Friis Calculator: https://www.pasternack.com/t-calculator-friis.aspx

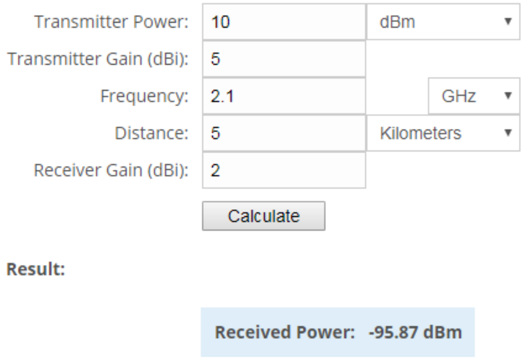
FRIIS PROPAGATION EQUATION

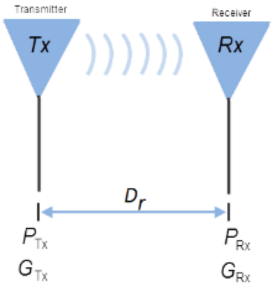
$$\frac{P_r}{P_t} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2} = \frac{G_t G_r}{\left(\frac{4\pi r f_c}{c}\right)^2}$$

$$P_r|_{dB} = P_t|_{dB} + G_t|_{dB} + G_r|_{dB} + 20 \cdot log_{10} \frac{\lambda}{4\pi r}$$

- If we had fixed area for the antenna, the antenna gain (directivity) needs to increase with frequency
  - Realized using dish antenna or an ‘antenna array’
  - More on antenna array later (Section 2.9 in the textbook)

RX POWER

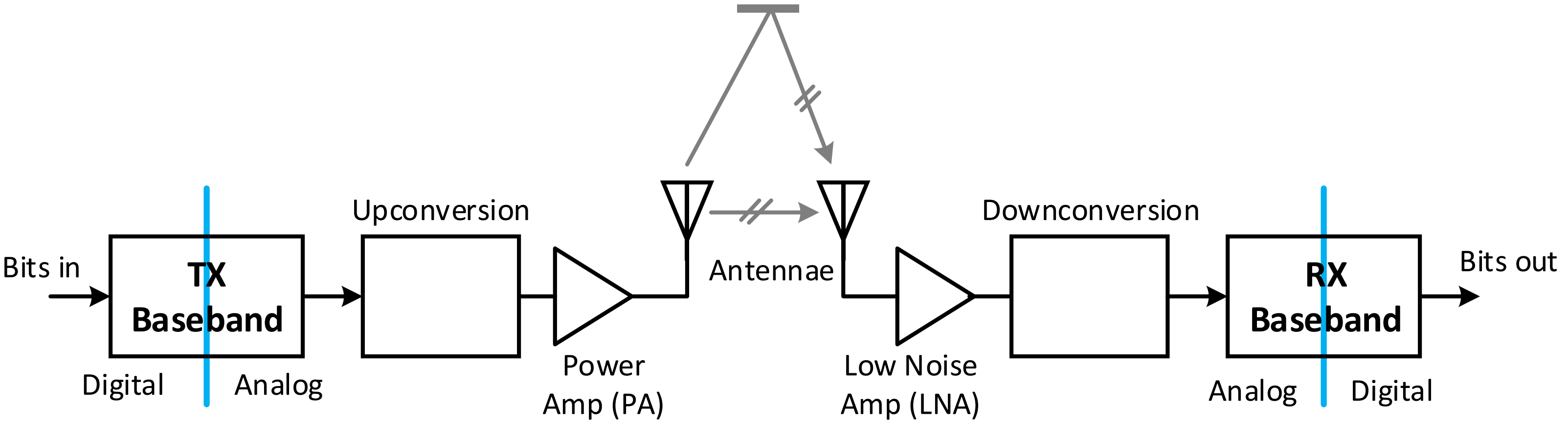




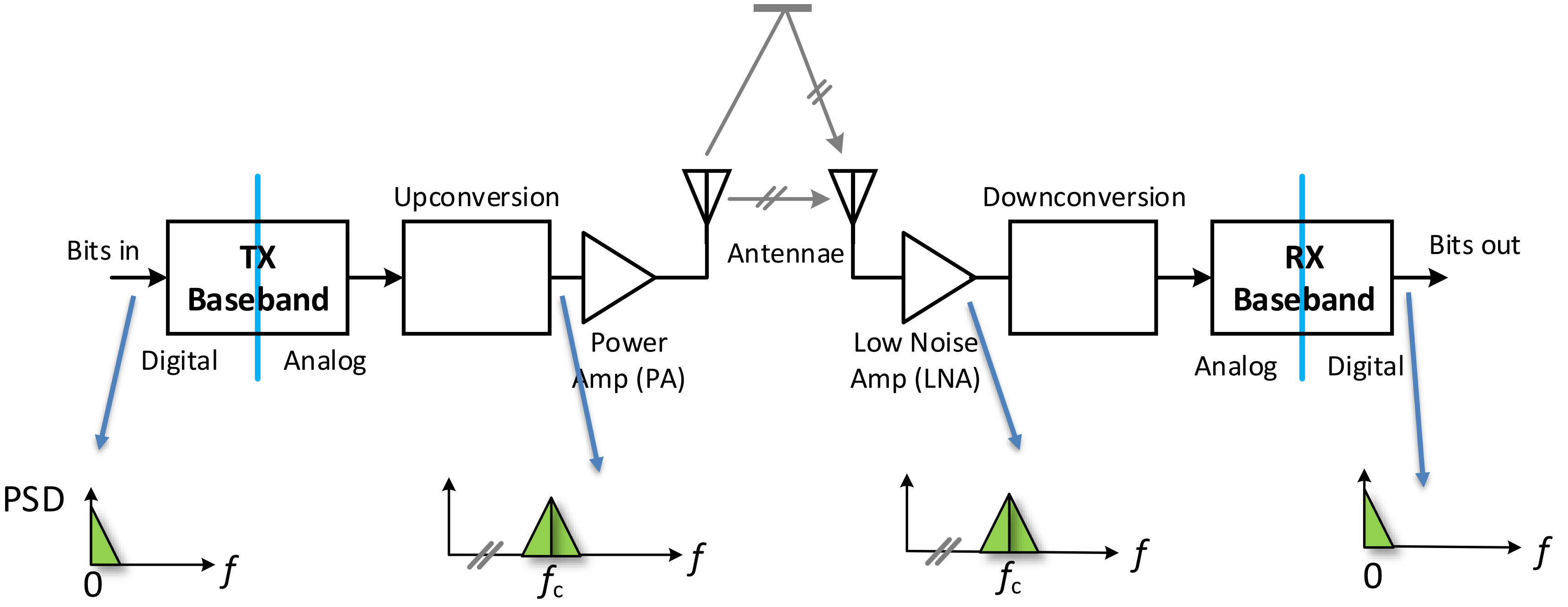
Friis Calculator: https://www.pasternack.com/t-calculator-friis.aspx

- Received signal is very weak, typically -80dBm to -120dBm
- Often drowned by large interferers (say >0dBm).

RF TRANSCEIVERS



RF TRANSCEIVERS



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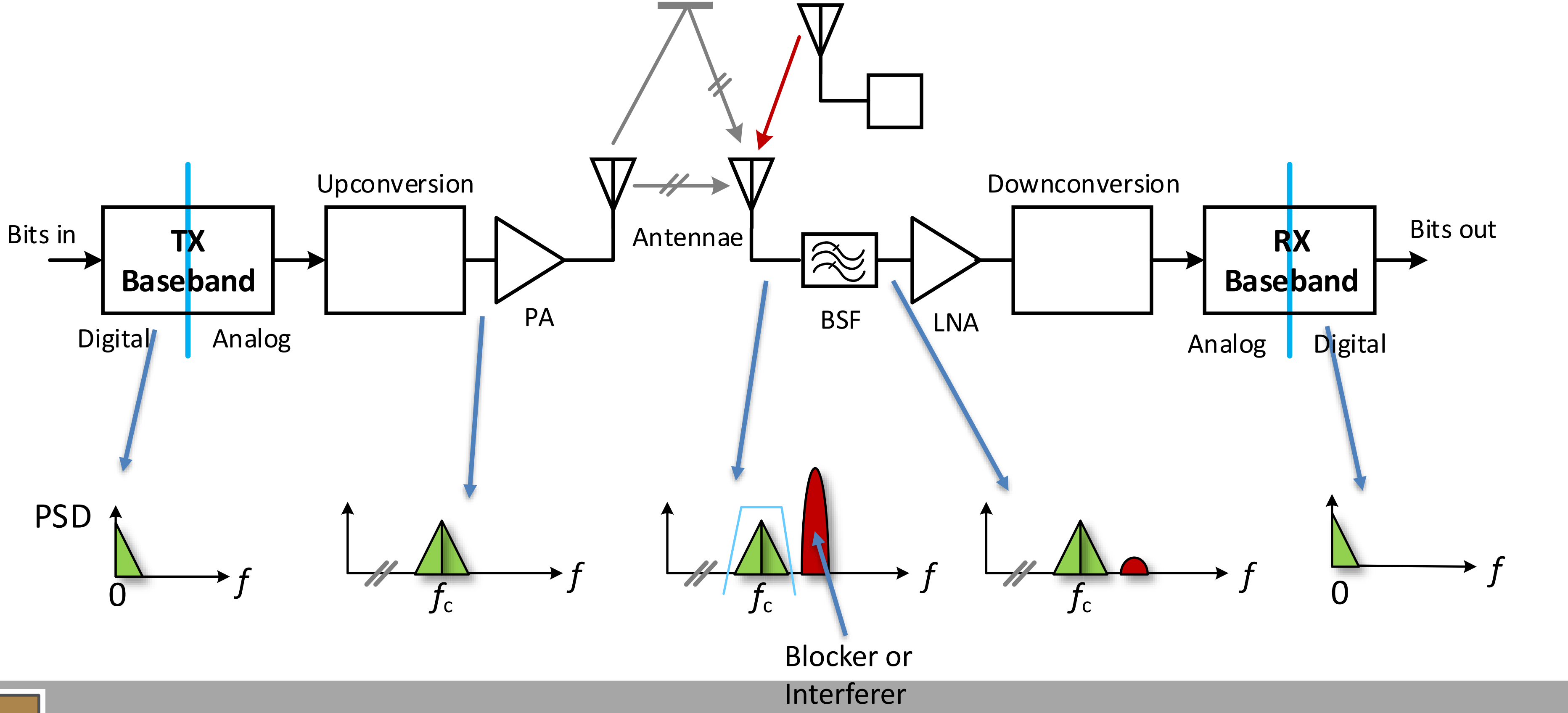
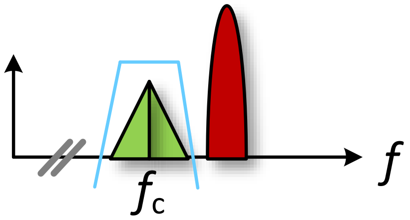


RADIO TRANSCEIVERS

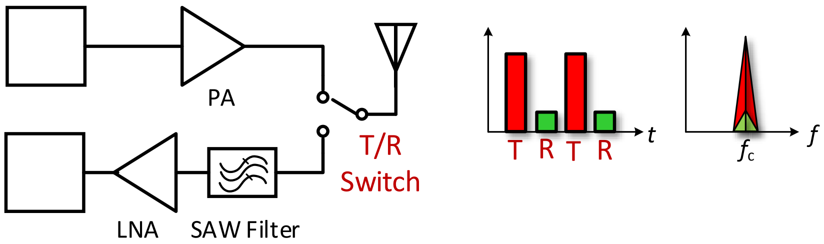
- A transmitter modulates a baseband signal to a higher carrier frequency and feeds and antenna with sufficient power
  - Should not distort the TX signal too much
- A well-designed receiver should perform
  - High-gain amplification of the received signal
  - Highly selective filtering of the desired signal
    - Reject adjacent channels, interferers, and image signal
  - Recovery of the intended information within error limits
- Processing narrowband analog signals with high selectivity and dynamic range

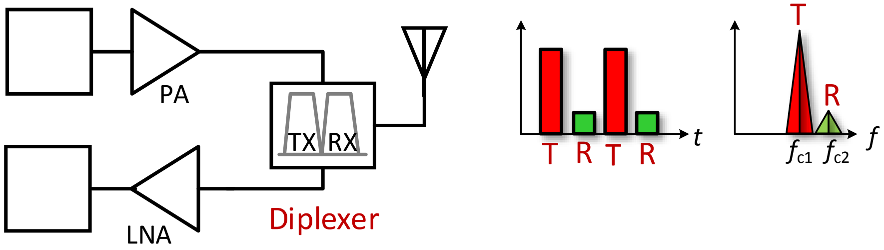


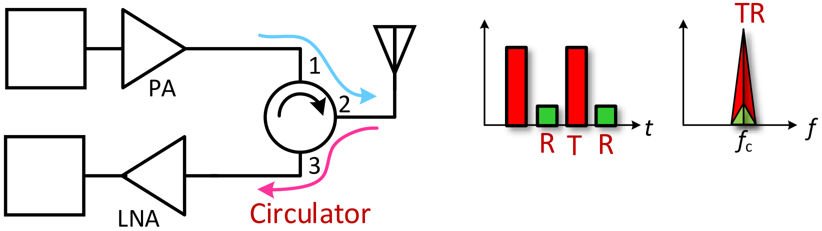
RADIO TRANSCEIVERS: ISOLATION

- Usually TX and RX don't operate simultaneously at the same carrier frequency
  - Frequency-division multiplexing (FDD) or
  - Time-division multiplexing (TDD) schemes used
  - Other methods of isolation
- Selectivity achieved using off-chip filters (SAW or MEMS)
- Isolation between TX and RX achieved using off-chip diplexers and isolators/circulators

RF TX/RX ISOLATION

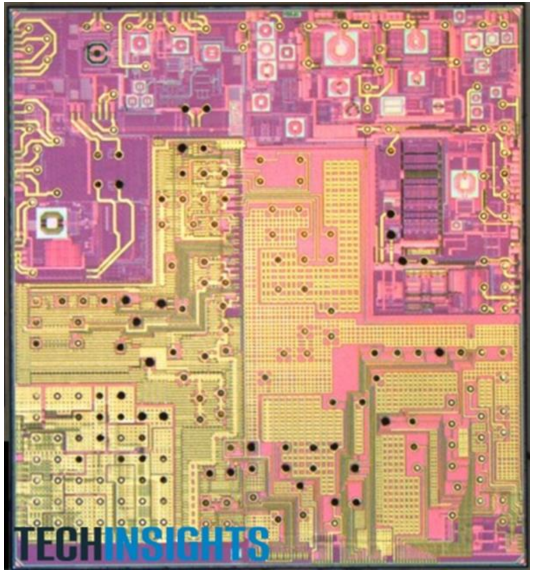






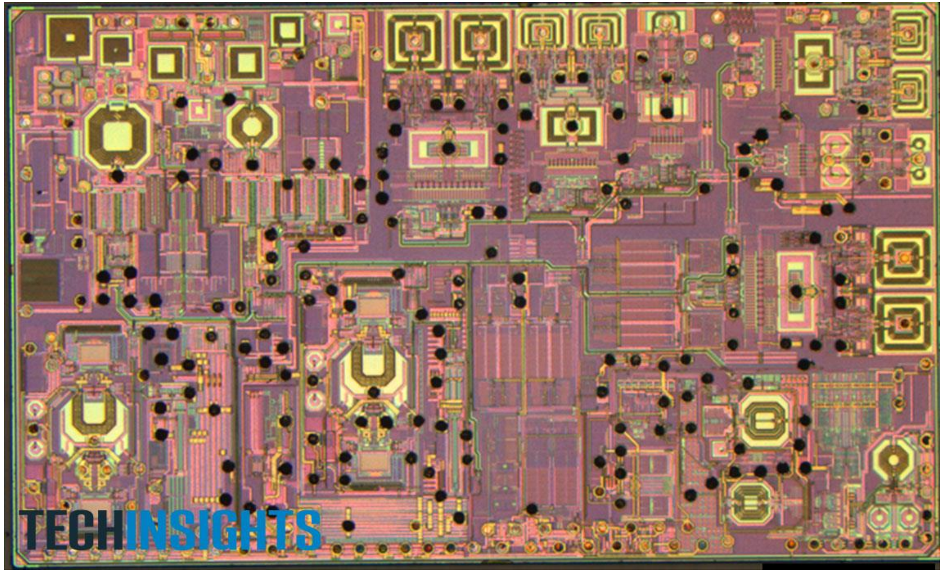
- Isolation usually not sufficient for simultaneous TX and RX
  - TX leaks to RX through package coupling and reflections
- Search full-duplex radios online for recent advances!

COMMERCIAL RFICS



BCM 4330 – Mobile Wireless

Single-band 2.4 GHz 802.11 b/g/n or dual-band 2.4 GHz and 5Ghz 802.11 a/b/g/n Integrated ARM® Cortex™-M3 processor and on-chip memory.



Qualcomm RTR8600 chip

Multi-band Multi-mode RF transceiver found in prominent Smartphones